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ABSTRACT

The purpose of this study was to investigate the effects of interactive learning strategies in the form of visually-based, real-time computer simulations on inductive learning by adults in physical science. The subjects were 160 upperclass undergraduate students who were enrolled in an introductory computer education class. The computer based instruction (CBI) content of the tutorial and simulation activities involved the physics principles of Newtonian mechanics. All instruction was presented at an introductory level intended for novices with emphasis on concept formation and application rather than mathematics. Three data sources were studied: performance, as measured by student scores on a posttest; comprehension monitoring; and response confidence. All instruction and testing was administered by computer. Subjects were randomly assigned to one of the treatment groups and they completed the computer lessons individually. A 2X3 factorial design was used. Two levels of Tutorial (Yes, No) were crossed with three levels of Simulation (Structured, Unstructured, None). The simulation activities were provided immediately after each of the four lesson parts in the tutorial. Inductive learning strategies consisted of the two simulation conditions presented as the sole learning experience. The no simulation, no tutorial condition acted as the posttest-only control. It was found that, while students in the Structured Simulation/No Tutorial condition performed similarly to students who received direct instruction via the tutorial, the former did not feel as confident in their answers to specific posttest questions as the latter. Follow-up surveys with the students indicated that they felt very uncomfortable with the unstructured simulations, and it is suggested that a lack of confidence may be among the consequences of providing adult subjects with experiential learning approaches rather than direct instruction. (35 references) (BBM)

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Authors:

Lloyd P. Rieber
M. Wayne Parmley

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Effects of Animated Computer Simulations on Inductive Learning with Adults: A Preliminary Report

Lloyd P. Rieber
M. Wayne Parmley
Texas A&M University

Two design features of the computer distinguish it from other educational media — greater display capabilities and the ability to provide continuous adaptive feedback. Relevant and sustained interactivity is central to instructional design (Gagné, 1985; Jonassen, 1988; Wager & Wager, 1985). The computer affords a wide range of interactive strategies at all levels of learning. Interactive learning strategies are usually grouped under the heading of practice. Practice that is designed to promote higher-level processing (Salisbury, 1988) often encourages students to use cognitive strategies such as informal hypothesis-testing to solve problems or resolve conceptual conflicts. Of the many available computer-based instruction (CBI) formats, simulations offer the most potential of exploiting both the display and interactive strengths of computers.

Simulations are constructed for two primary purposes: to study relationships in a model of a system (e.g. scientific simulations); and to teach users about these relationships (Duchastel, 1990-91). As an instructional tool, computer simulations allow users to have meaningful experiences within a system or domain through experimentation and discovery. Simulations can be designed to represent only a portion of the real world, thereby making an abstract situation more concrete. Users can generate and test hypotheses in a simulated environment by examining changes in the environment based on their input, but without the potentially undesirable consequences of reality. Thus, simulations help to enable students to learn specific problem solving strategies by receiving immediate feedback on decisions made while in the structured environment of the simulation (Gress, 1982). In instructional settings the student interacts with the simulation and observes the computer output as either verbal or visual feedback (Vernezky & Osin, 1991). Feedback can also be presented in real time, accelerated time, or decelerated time. This can be especially useful when the simulated event either occurs too fast (e.g. an internal combustion engine) or too slow (e,g, deforestation) in real life for the feedback to have any meaning.

Computer-based microworlds, which simulate information and relationships of complex systems in areas such as mathematics, science, and geography, also offer promise in the design of interactive learning environments (Collins, Adams, & Pew, 1978; diSessa, 1982; Papert, 1981; White, 1984; Montague, 1988). Microworlds, a concept derived from constructivism, are small representations of content areas or domains (Forman & Pufall, 1988). Microworlds are often confused with simulations. Although microworlds and simulations can remain entirely distinct, the characteristics of the two can overlap or even be synonymous depending on their design and on how each is used in a learning interaction. A microworld is often defined as a representation of the simplest model of a domain that can be recognized by an expert and, most importantly, which also matches the user's abilities, interests, and experiences.

Simulations, on the other hand, are generally designed to mimic real life experiences, such as a flight simulator. When designed as microworlds, simulations allow learning contexts and situations to be created which extend beyond the walls of a classroom — students can try to survive a trip to the South Pole, save a beached whale, run a campaign for President of the United States, or explore the systems of the human body. Simulations, especially those with game-like features, offer the potential for intrinsically motivating activities (Malone, 1981; Rieber, 1991). For simplicity, we will use the term "simulation" throughout this paper to refer to learning environments which incorporate features of microworlds.

The instructional effectiveness of a simulation is determined by three major aspects of its design: the scenario, the underlying model, and the instructional overlay. The scenario recreates a real life situation and determines what happens and how it takes place. The model is usually a mathematical formula that reflects the causal relationships that govern the situation. The instructional overlay includes the instructional design features of a simulation and how they should be used to optimize instruction. Simulators also enhance the transfer of learning by teaching complex tasks in an environment that approximates the real world setting (Reigeluth & Schwartz, 1989). Simulations provide students with

opportunities to study processes, procedures, and phenomena that either cannot be taught under any circumstances or cannot be easily taught using traditional methods (Hannafin & Peck, 1988). Simulations differ from interactive tutorials, which help students learn by providing information and using appropriate question-answer techniques. In a simulation the student learns by performing the activities to be learned in a context that is similar to the real world (Alessi & Trollip, 1985).

Simulations can perform many instructional functions. They are frequently used as follow-up practice strategies for higher-level learning during traditional instructional designs. This type of approach is based on a deductive learning model, where students are formally introduced to a concept or a principle, followed by practice. A deductive approach provides structure to guide a student during an exploration of the simulated environment in predetermined steps, thus allowing for directed practice. Recent studies have reported successful applications of structured simulations as practice activities in the teaching of physical science (Rieber, 1990a, Rieber, 1990b; Rieber, Boyce, & Assad, 1990). One of the most important components of these structured simulations has been the use of animation as visual feedback. Animation can provide a constant stream of visual feedback based on moment-to-moment student input.

In addition, simulations can also be used in inductive learning strategies. Inductive approaches to learning have students interact with instances of subject matter before generalities are introduced and explained. An inductive approach is based on letting students discover the structure of the subject matter on their own (Bruner, 1966; Slavin, 1988). The same simulation used as practice in a deductive approach can also give a student the opportunity to freely explore an environment and learn by discovery or through game-like contexts. Do students need the added structure of guided activities called for by deductive approaches, or can they learn by just being given the opportunity to interact freely with a rich model of a learning domain? There is a need to continue the research of animation-based interactive strategies on the computer beyond their use as traditional practice activities.

The purpose of this study was to investigate the effects of interactive learning strategies, specifically visually-based, real-time computer simulations, on inductive learning of adults in physical science.

SUBJECTS

The subjects consisted of 160 upperclass undergraduate students (juniors and seniors) who were enrolled in an introductory computer education class. Participation was voluntary with extra credit in the course provided as an additional incentive to participate.

MATERIALS

The CBI content of the tutorial and simulation activities involved the physics principles of Newtonian mechanics. The tutorial was divided into four parts. The first part reviewed fundamental background vocabulary and concepts, such as mass, weight, inertia, and force. This part also formally presented Newton's first law of motion. The second part introduced Newton's second law of motion and then described applications of Newton's first and second laws given equal forces in opposite directions in one-dimensional space. The third part extended the application of Newton's first and second laws to include the effects of unequal forces in one-dimensional space. The fourth part introduced and explained applications of these principles in two-dimensional space. All instruction was presented at an introductory level intended for novices. The lesson was designed to exclude as much formal mathematics as possible and instead concentrated on concept formation and application.

DEPENDENT MEASURES

Three data sources were studied: performance, as measured by student scores on a posttest; comprehension monitoring; and response confidence. The posttest consisted of 27 rule-using questions using a multiple-choice format (1 answer and 4 distractors). The posttest measured student performance on the four lesson objectives previously described above. KR-20 reliability of all 27 questions was .86.

At various points during the instructional treatment, students were prompted to answer the following question: "If you were given the posttest right now, what do you think your score would be?" Students answered from 0% to 90%, in multiples of 10%. These introspection data on students' perceived level of learning during the lesson were designed to be an informal assessment of their comprehension monitoring. For this analysis, comprehension monitoring is operationally defined as the students' answer to this question immediately before the administration of the posttest. Students were also asked this question before they began the lesson, in order to test whether or not the groups were similar in the perception of how much they already knew about the material. No significant differences were found among the groups at the start of the experiment, $F(5,154)=1.70$, $p>.1$, $MS_e=4.31$. On average, students felt they would get about 38% of the posttest questions correct if given the test immediately.

Response confidence during the posttest was also collected. Immediately after answering each question,

students were asked to rate how confident they were in their answer on a Likert-type scale from 1 to 9 where 1 was "I guessed" and 9 was "I know I'm right."

PROCEDURES

All instruction and testing was administered by computer. Subjects were randomly assigned to one of the treatment groups as they reported to the computer lab. Once instructed to begin, subjects completed the computer lesson individually. The posttest was automatically administered to each student upon completion of the four lesson parts. Approximately 90 minutes were needed to complete the lessons in each experiment.

DESIGN

A 2 X 3 factorial design was used in this study. Two levels of Tutorial (Yes, No) were crossed with three levels of Simulation (Structured, Unstructured, None). The respective simulation activity was provided immediately after each of the four lesson parts in the tutorial. Deductive learning strategies were comprised of conditions which included the tutorial. When paired with the tutorial, each simulation condition acted as follow-up practice in the tradition of direct instructional methods. Inductive learning strategies were comprised of the two simulation conditions presented as the sole learning experience. The no simulation, no tutorial condition acted as a posttest-only control.

The structured simulation condition consisted of a series of four separate computer simulations in which students were given increasing levels of control over a simulated, free-floating object (called a "starship"). This activity is termed "structured" because each simulation presented a controlled number of new subskills to students. Each successive simulation incorporated the subskills from the preceding simulation.

The unstructured simulation condition consisted of an open-ended and unstructured simulation in which students assumed full control over the animated starship from the very beginning. The simulation was presented using a game-like context. Students were provided with the goal of "docking" their animated starship with a "space station" (represented by a circle on the screen). A scorekeeping feature was built into the game in order to provide an extra level of challenge as well as to help students see whether or not their skills were improving. Students were given a total of 10 trials with this activity to provide a similar level of exposure as that experienced by students in the structured simulation condition. Figures 1 and 2 illustrate examples of the structured and unstructured simulation activities.

Statistical procedures included analysis of variance (ANOVA) on each of the dependent measures and Tukey's studentized range test for follow-up multiple-comparisons on means.

RESULTS AND DISCUSSION

A significant interaction was found between Tutorial and Simulation, $F(2,154)=7.13$, $p<.01$, $MS_e=279.89$, on posttest performance, as illustrated in Figure 3. Students in the Structured Simulation/No Tutorial condition (mean=74.5%) performed as well on the posttest as any of the three Tutorial groups (mean=83.0%). All of these four conditions performed significantly better than students in the control condition (No Tutorial/No Simulation) (mean=54.1%). Student scores in the Unstructured Simulation/No Tutorial condition (mean=67.6%) did not vary significantly from those of the control condition. These performance results support the hypothesis that adult students would be able to induce and apply relevant physical science rules given experiences with real-time computer simulations. However, the simulation was only effective in promoting inductive learning when it was structured so as to introduce a limited number of learning variables at a time. Learning was obviated when this structure was removed from the simulation and subjects were placed in a simple, yet open-ended simulation. It should be noted that the tutorial appeared to be an especially potent treatment variable and probably masked the effects of the simulation activities when they were paired with it.

A significant interaction was found between Tutorial and Simulation, $F(2,154)=4.99$, $p<.01$, $MS_e=3.15$, on comprehension monitoring, as illustrated in Figure 4. Follow-up analyses indicated two groups. Those who were given the tutorial or the structured simulation felt that they had learned significantly more than students given only the unstructured simulation or no instruction. Given only the unstructured simulation, therefore, students perceived they had not learned anything and felt totally unprepared for the posttest. However, students given only the *structured* simulation, but no tutorial, felt as though they had learned as much as students given the traditional tutorial.

The analysis of students' response confidence during the posttest also indicated a significant interaction between Tutorial and Simulation, $F(2,154)=4.53$, $p<.05$, $MS_e=2.77$, as shown in Figure 5. Follow-up analyses indicated three distinct groupings. Subjects in all three Tutorial conditions indicated the strongest level of confidence in their answers to posttest questions (mean=7.6). Next in order of response confidence were subjects in the Structured Simulation/No Tutorial condition (mean=6.1). Finally, subjects in both the Unstructured Simulation/No Tutorial condition and No Simulation/No Tutorial control condition constituted the third and lowest response confidence ratings group

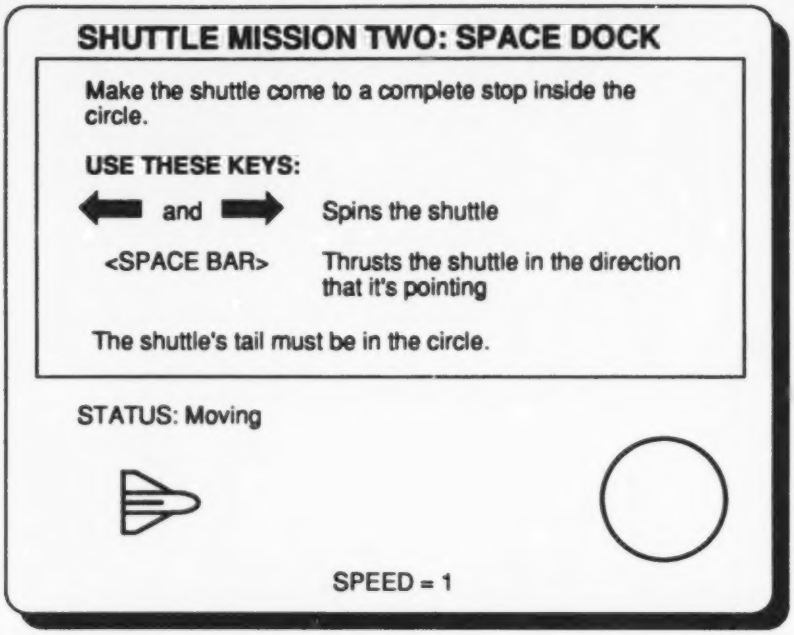
SHUTTLE MISSION TWO: SPACE DOCK
Make the shuttle come to a complete stop inside the circle.
USE THESE KEYS:
and
Spins the shuttle
<SPACE BAR>
Thrusts the shuttle in the direction that it's pointing
The shuttle's tail must be in the circle.
STATUS: Moving
SPEED = 1

FIGURE 1. *An example of a structured simulation activity.*

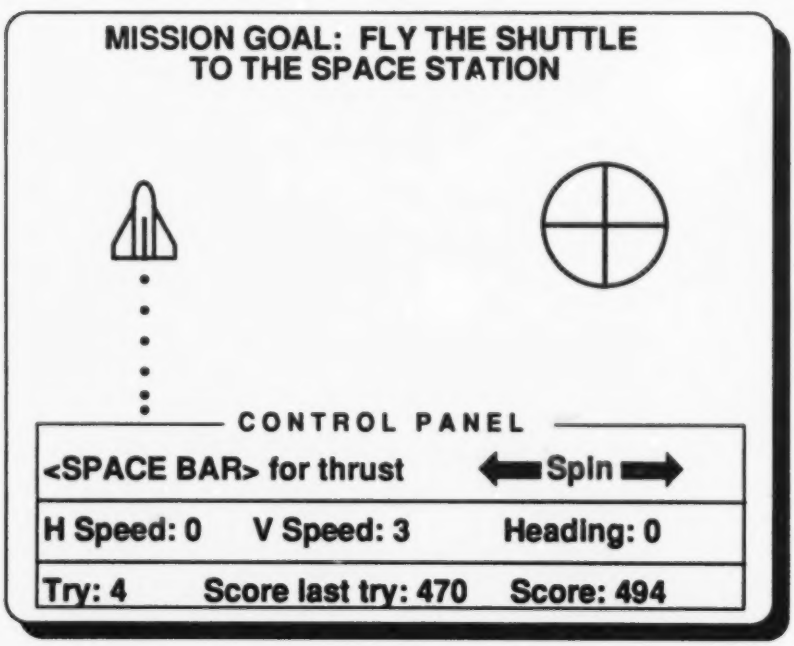

FIGURE 2. *An example of an unstructured simulation activity.*

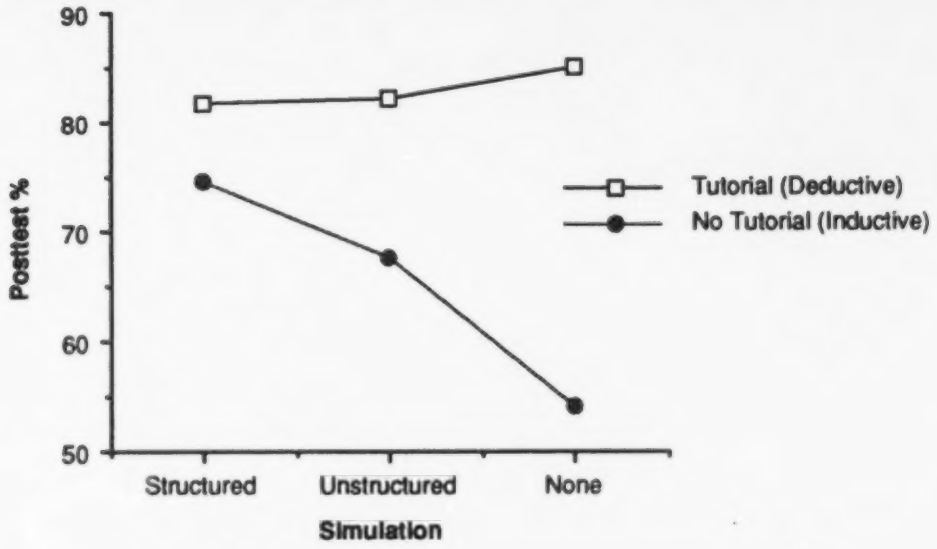

FIGURE 3. *Interaction between Tutorial and Simulation on the Performance Data*

(means=4.7 and 4.4, respectively). This pattern is similar to that of the comprehension monitoring data in that students given only the structured simulation felt more confident than students given only the unstructured simulation. However, students given only the structured simulation obviously lost confidence while answering the questions, as they were distinctively less confident than students given the tutorial.

So, while students in the Structured Simulation/No Tutorial condition performed similarly to students who received direct instruction via the tutorial, the former did not feel as confident in their answers to specific posttest questions as the latter. Hence, a lack of confidence may be among the consequences of providing adult subjects with experiential learning approaches, rather than direct instruction. Follow-up surveys with the students indicated that they felt very uncomfortable with the unstructured simulations — they had expected and wanted more structure. When adults are engaged in what they perceive to be a formal, or school-like, learning experience, they expect school-like learning environments to best aid their learning, and may actually resist the opportunity to learn by discovery. This point has been echoed by adult educators (Seaman & Fellenz, 1989).

A follow-up study has been conducted using children, although data have not, as yet, been analyzed. It is expected that children may be more receptive to learning from open-ended activities which offer little resemblance to "school-like" tasks.

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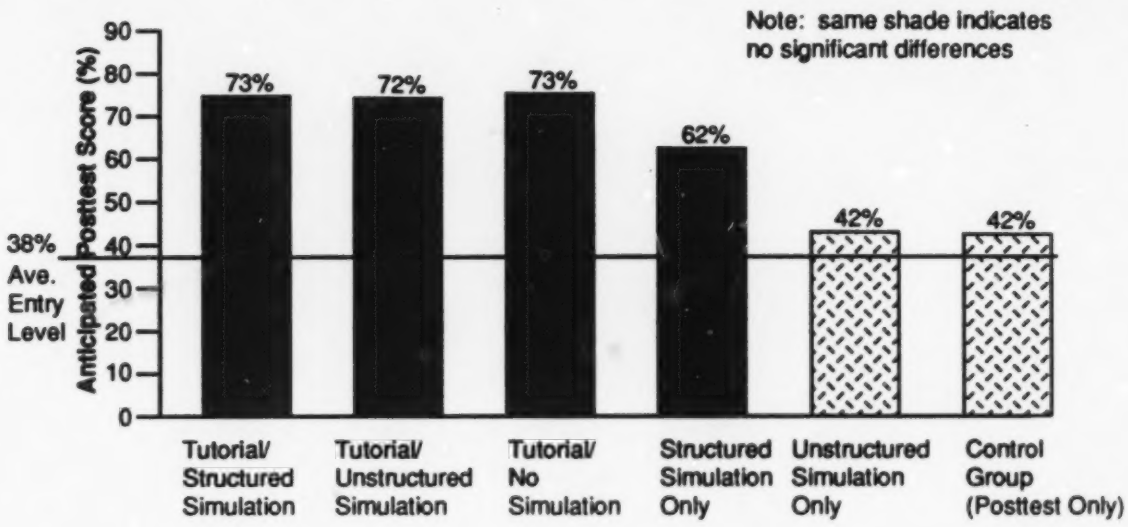

FIGURE 4. *Interaction between Tutorial and Simulation on comprehension monitoring data.*

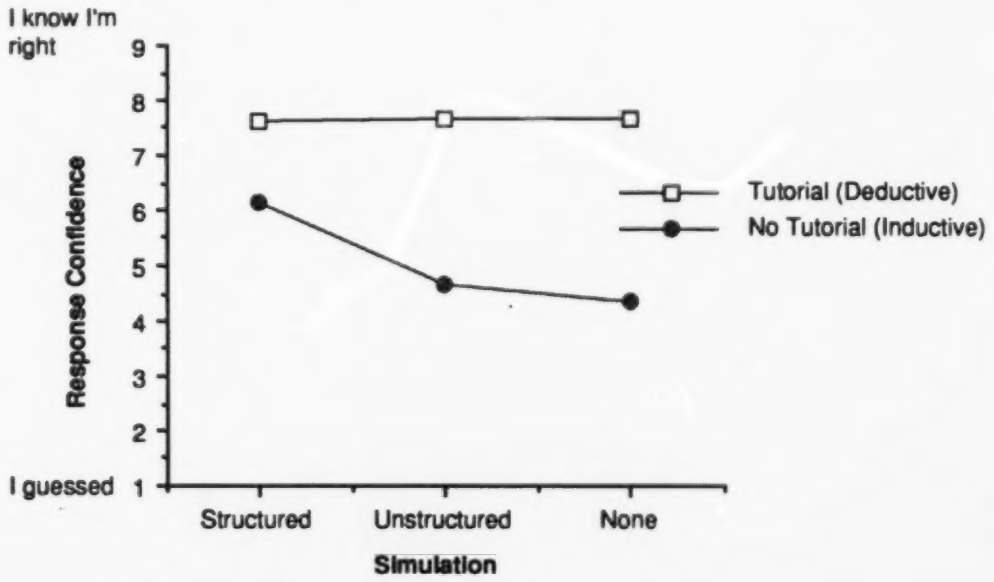

FIGURE 5. *Interaction between Tutorial and Simulation on the response confidence data.*

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